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SOLAR PROBE WITH BURNER II PROPULSION MODULUS

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SOLAR PROBE WITH *BURNER II* PROPULSION MODULUS

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1. Determination of the Optimal Characteristic Values for a Solid-Fuel Propulsion System for Putting a Solar Probe into Orbit

We present here a detailed discussion of what orbits and power outputs could be achieved with various solid-fuel motors; it must be emphasized that we are dealing here not merely with a simple solid-fuel motor, but with a fully equipped propulsion modulus with solid-fuel motor ("FESTAM") [Feststoff-Antriebsmodul; solid-fuel propulsion modulus].

The ATLAS SLV-3X-CENTAUR, in the form in which it will be in use from 1968 on, is assumed as the carrier rocket. The data for this improved carrier are contained in the study *Solar Probe* (RF 77 - ST), page 32. In comparison to the present version of the ATLAS-CENTAUR the amount of fuel and the engine thrust of the ATLAS have been increased, while it has been possible to raise the specific impulse of the RL-10 motor to 443 sec.

Cape Kennedy is thought of as the launching place for the subsequent experiments, and the beginning of July as the launching time, since in that case the required hyperbolic excess velocity is lowest. It amounts in that case to 9353 m/sec for an orbit of 0.30 A.U.

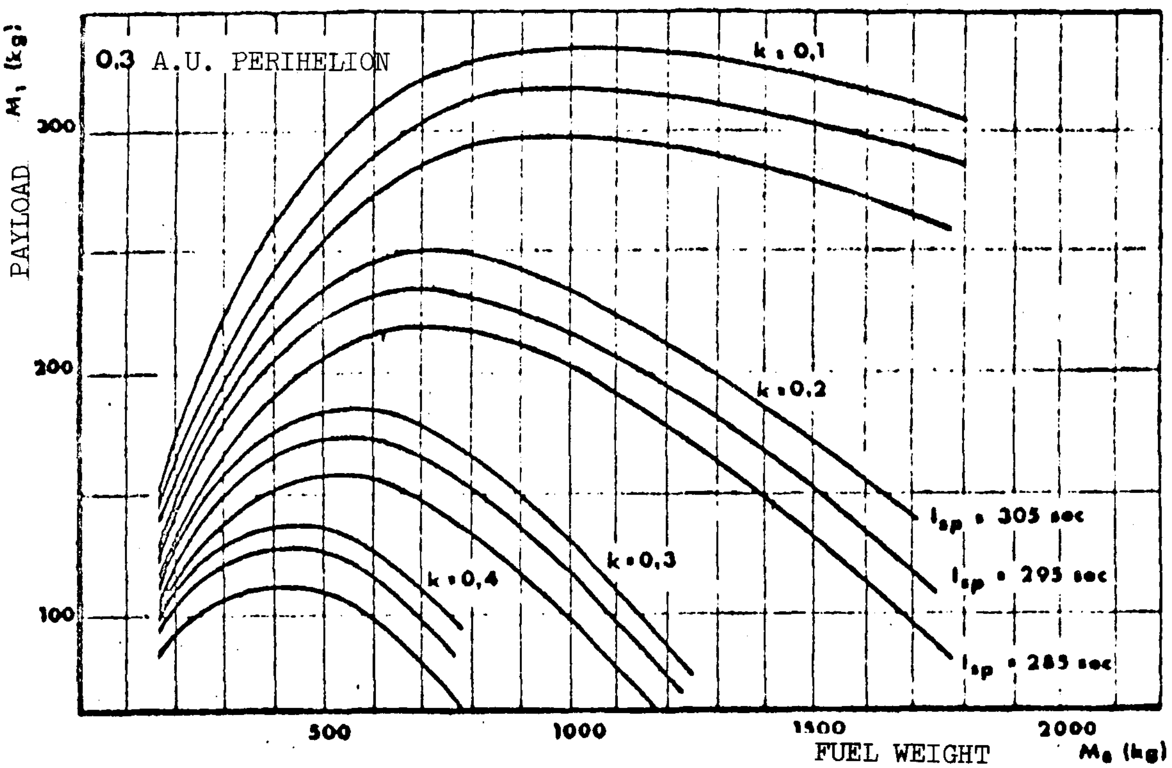


Figure 1. General diagram of the payload of the ATLAS-CENTAUR rocket as a function of the design weight and the specific impulse of the solid-fuel propulsion modulus.

The other conditions were also so chosen as to maximize the payload.

The range of variation for the characteristic values of solid-fuel moduli was chosen as follows:

Specific impulse .... 285 to 305 sec
Fuel weight ....200 to 2000 kg
Design factor ....0.10 to 0.40
(k = net weight/fuel weight)

With these characteristic values a series of orbit calculations were carried out, which have also been analytically evaluated and supplemented. The results are shown in Figure 1.

The diagram shows that a solid-fuel stage ("FESTAM") under certain conditions could provide an adequate minimal payload of about 150 kg for an orbit with a 0.3 A.U. perihelion.

Table I and the curves interpolated with these values in Figure 2 serve for estimation of the actual power output values of solid-fuel motors.

In Figure 2 a distinction is made between "solid-fuel stages" with exterior covering and "solid-fuel propulsion moduli" without exterior covering but with complete guidance and control systems.

Table I. Data for Solid-Fuel Propulsion Systems and Complete Stages

Designation	Fuel Weight (kg)	Net Weight of Propulsion System (kg)	Net Weight of Propulsion System (%)	Net Weight of Stage (kg)	Net Weight of Stage (%)
BURNER II Thiokol TE 364.2	560	65	11.6	210	37.5
SCOUT Fourth Stage FW-4S XSR-57-UT-1	280	27	9.6		
DIAMANT Third Stage Rubis	641	70	10.9		
SCOUT Third Stage Antares II X-259-A5	1178	100	8.5	347	29.4
DELTA Third Stage X-248-A5	207	27	13		
DIAMANT Second Stage Topaze	2260			670	29.6

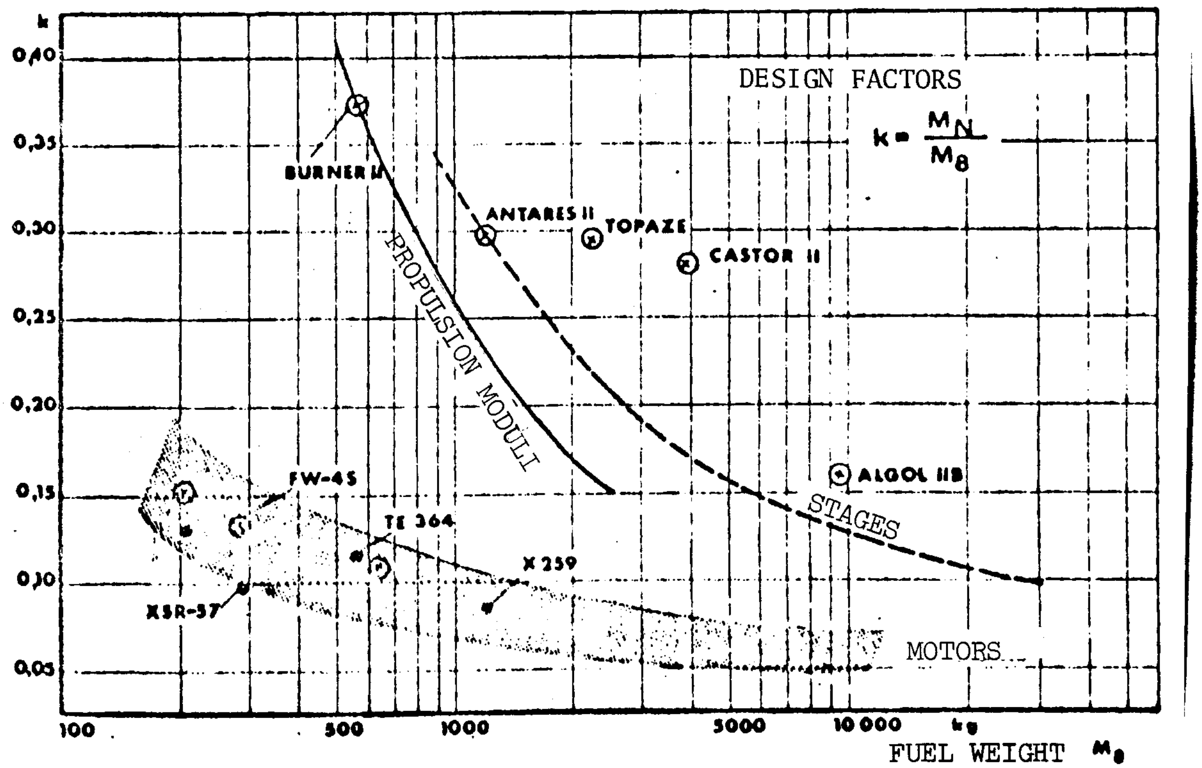


Figure 2. Design factors of solid-fuel motors, propulsion moduli, and stages.

The curves for structural weight or k-factor are based on the present state of the art, so that some older stages (Topaze, Castor II) lie above the curve.

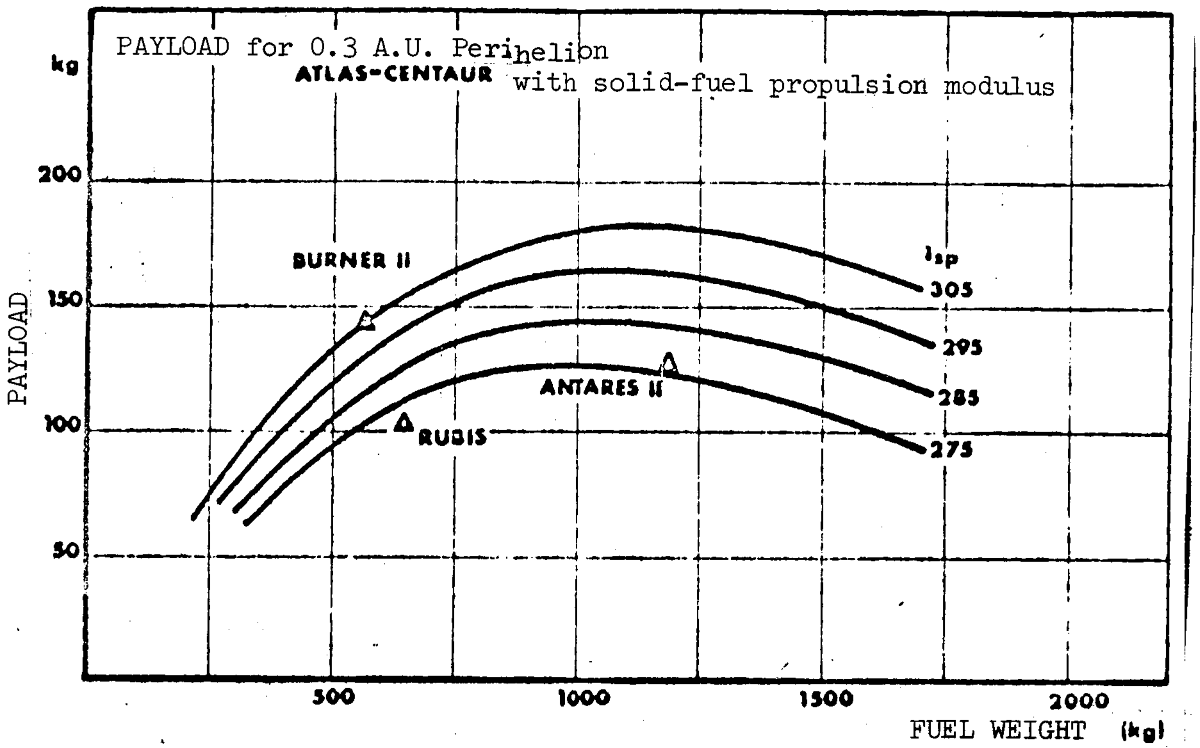


Figure 3. Payload as a function of fuel weight and specific impulse of the propulsion modulus.

Figure 3 shows the resulting payload for a solar probe as a function of fuel weight and specific impulse. Two existing solid-fuel stages ("Rubis" and "Antares") are also plotted in, as well as the new propulsion modulus "BURNER II." While this last has not got the optimal fuel weight, it has the highest power output. The lower fuel weight keeps the thrust and consequently the acceleration within controllable bounds.

The idea therefore suggests itself of concentrating on BURNER II as a propulsion modulus, especially as this device is said to show a reliability of 96%. (This means that only one launching would be necessary.)

The possible payload range with BURNER II as propulsion modulus is shown in Figure 4. With the present fuel weight of 560 kg the payload of 143 kg is extremely scanty for 0.3 A.U. (estimated weight of solar probe without redundancy = 140 kg). It is therefore probable that only a perihelion of 0.31 A.U. can be attained unless the fuel weight is increased or other improvements carried out on the carrier rocket.

A perihelial distance of 0.29 appears to be realizable as a maximum, but this would require raising the fuel weight to about 1000

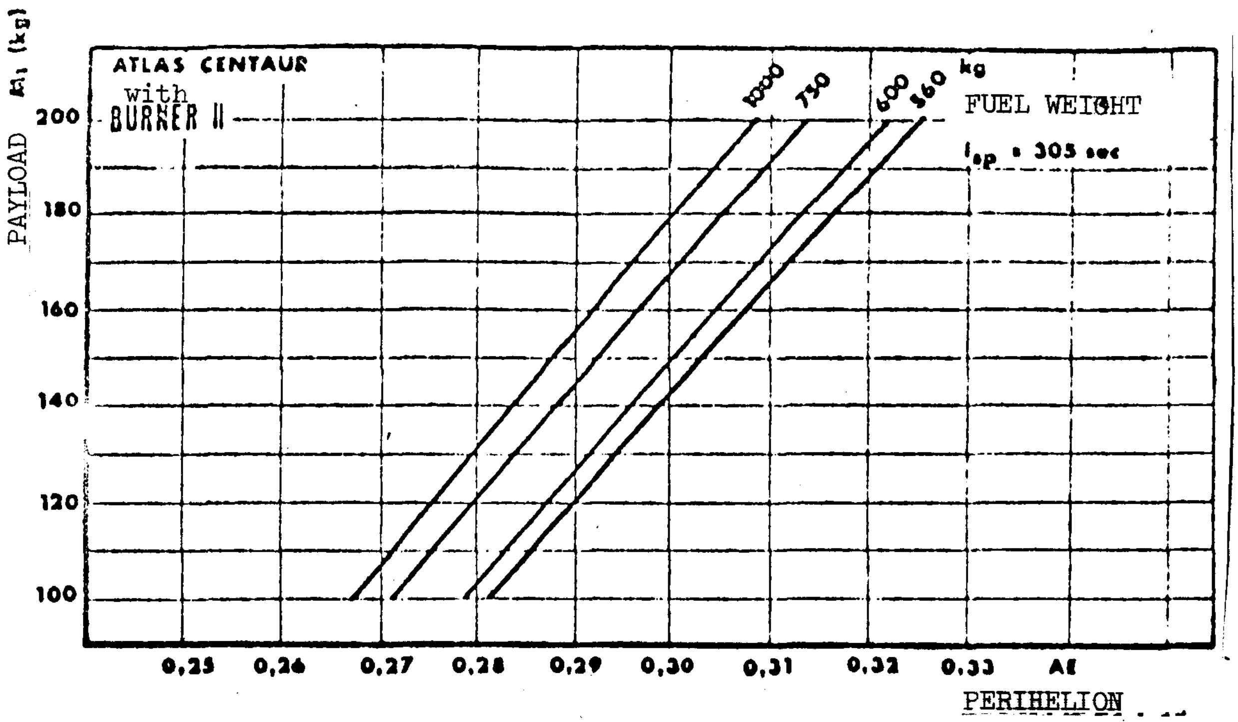


Figure 4. Payload as a function of perihelion for ATLAS-CENTAUR-BURNER II.

kg and would bring up a number of technical problems. By interpolation of the curves of Figure 4 intermediate values for fuel weights between 560 and 1000 kg may also be obtained.

The BURNER II propulsion modulus is described in more detail in the next chapter.

2. Description of the BURNER II Stage

2.1 General

BURNER II is the first and so far the only stage with solid-fuel propulsion that has been developed with complete guidance and control systems for general space-travel purposes.

The development was done by the firm of Boeing in 1965-66 under USAF contract. The first launching with a THOR rocket was successfully carried out on 15 September 1966.

In BURNER II the greatest value was placed on low costs and high reliability. For example a reliability of 96% had to be demonstrated, and that was possible only by the use of components already existing and tested. The diameter of BURNER II is 165 cm, the height 173 cm, and the total weight 770 kg. The following table gives a breakdown of weight, but is only estimated; the precise figures have not yet been released.

Weights, BURNER II (Estimated)

		kg
M2	Electronic Equipment	
	M21 Reference platform with gyroscopic speed control	9.5
	M22 Electronic guidance equipment	2.0
	M23 On-board control system	5.0
	M24 Telemetry transmitter	2.5
	M25 Transponder	1.0
	M26 Measurement data processing	6.0
	M27 Decoder	4.0
	M28 Command receiver	1.5
	M29 Antennas	2.0
		33.5
M3	Command Destruction System	
	M31 Main battery	5.0
	M32 Control switch for ignition and self-destruction	3.0
	M33 Explosive charge	1.5
	M34 Battery for self-destruction in the Centaur	-
		9.5
M4	Electric Power System	
	M41 Battery (see M31)	-
	M42 Regulator	0.5
	M43 Transformer	3.5
	M44 Cable system	4.0
	Power supply 1.3	
	Control cables 0.5	
	Measuring devices 1.2	
	Antennas 0.4	
	Cable clamps 0.6	
	M45 Plugs and couplings	7.0
	~~M46 Measurement transmitter~~	10.0
		25.0
M5	Guidance System	
	M51 H_2O_2	17.0
	M52 N_2 gas	1.5
	M53 Tanks	2.0
	M54 Valves	6.5
	M55 Tubes and hoses	6.0

		kg
	M56 Motors 10 kp	5.0
	M57 Motors 1 kp	1.5
		39.5
M6	Structure	
	M61 Engine support	9.0
	M62 Payload support	4.0
	M63 Remaining structure	14.0
	M64 Reinforcements	9.0
	M65 Framing bolts + springing system	1.5
		37.5
M7	Engine	
	M71 Chamber with nozzle	65.0
Net Weight		210.0 kg
Weight of Fuel		560.0 kg
Total Weight		770.0 kg

2.2 Engine

The stage uses the spherical Thiokol solid-fuel engine TE-364.2, developed for the SURVEYOR project. It has a specific impulse of 306 sec, the highest of all solid-fuel engines ready for production. The period of combustion is 43 seconds, the thrust 4000 kp on the average (5000 kp maximum).

The weight is 625 kg, including 560 kg of fuel. The diameter of the engine chamber is 94 cm; the nozzle is sunken and has an expansion ratio of 53:1. The engine has a length of 133 cm including the (sunken) 74-cm nozzle.

The fuel used consists of polybutadiene acryl nitride with an admixture of aluminum (PBAA) and ammonium perchlorate.

2.3 Control and Guidance

The guidance system works with H_2O_2 (hydrogen peroxide) motors and consists of a system that was developed by the firm of Kidde for the SCOUT third stage. The motors have 10 kp thrust each. An additional system with 8 nitrogen gas nozzles provides for twist stabilization and fine positional regulation.

The inertial reference system is made by the firm of Honeywell (also from the SCOUT program).

The programming device allows for 28 signals with any timing between 0 and 2621.4 seconds at 0.01 second intervals.

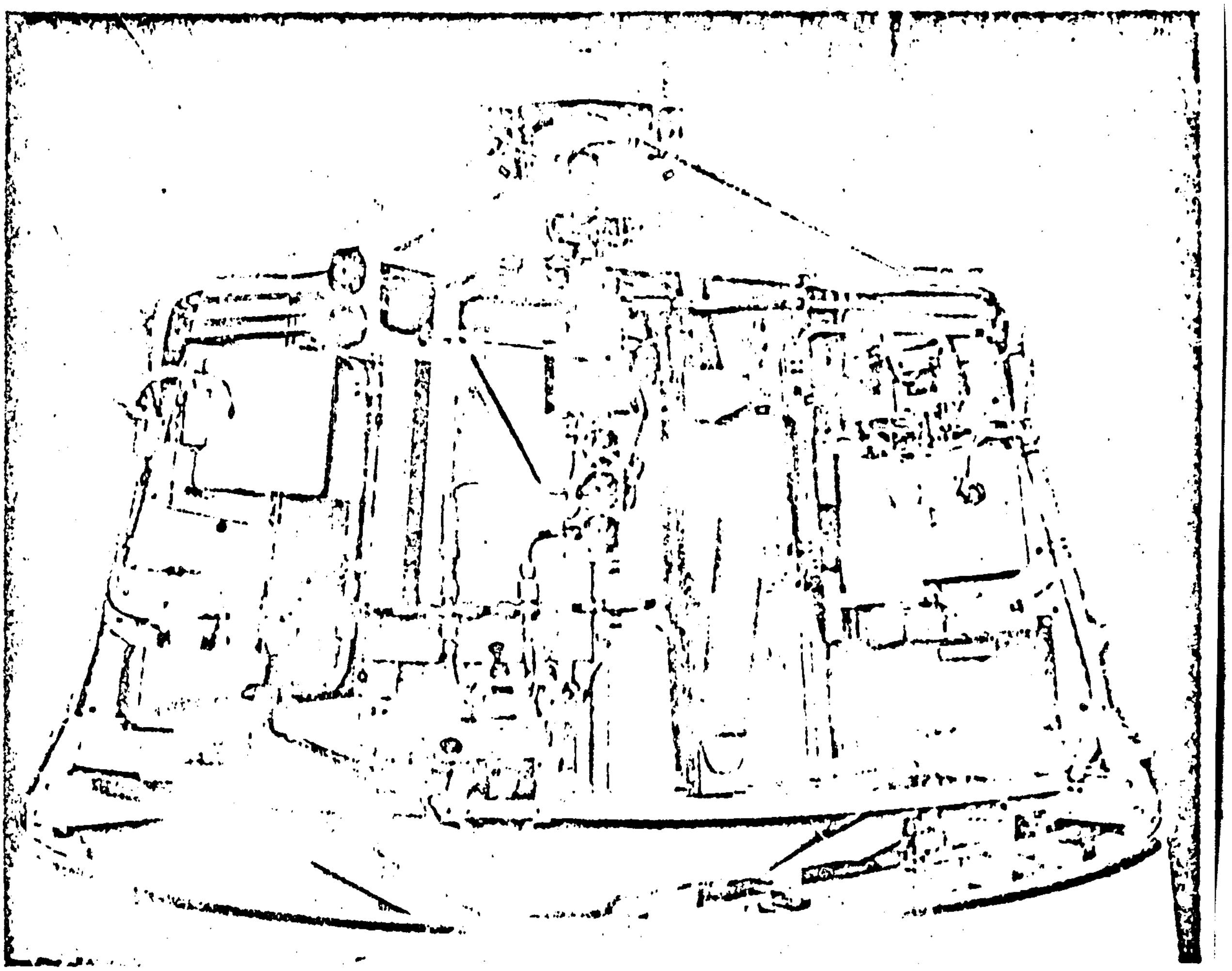


Figure 5. Equipment and structure of BURNER II.

2.4 Equipment

The telemetry system has 53 channels and is a modification of the MINUTEMAN system. It costs $32,370 per installation.

The checkout system was developed by Boeing (cost, $150,000 including preparations for launching).

2.5 Other Data

The BURNER II is being produced in series; eight have been ordered by the USAF, and other orders are in prospect. The price is $440,000 each.

The cost of development ran $6,500,000, the period of development 15 months. With BURNER II the THOR rocket can put payloads into a low orbit which lies between those of SCOUT and THOR-AGENA.

Studies have already been done of the use of BURNER II with ATLAS-

AGENA, ATLAS-CENTAUR, TITAN, and SATURN. (The payload of TITAN III C for a 24-hour orbit could for example be raised by BURNER II from 950 kg to 1340 kg.)

3. Sketch of a Solar Probe for Use with BURNER II

The nature of the propulsion modulus influences the design of the probe. When BURNER II is used the type of installation and the relatively high combustion-cutoff acceleration must be taken into account.

Both factors were considered in the concept illustrated in Figure 6. Expanded demands of the experimenters with regard to weight and installation conditions were also taken into account. It was also possible to provide some technical improvements.

The probe is completely regulated as to position, only an accuracy of 1 to 2° with reference to the main axis, which is directed toward the sun, being required.

This solution was found to be optimal as regards weight and cost after comparison of all possible solutions. Positional stabilization with orientation toward the sun is optimal for three of the five experiments (magnetic field, zodiacal light, and meteoroid experiments); in the other two experiments exploration in the plane of the ecliptic would be most favorable. This can be achieved by setting the equipment for each of the experiments on a rotating table whose axis is perpendicular to the ecliptic. In this case the speed of rotation can also be optimally adjusted (Figure 7).

This solution then gives ideal conditions of installation for *all* the experiments -- better than in any spin-stabilized probe. The latter has essential shortcomings in this case with respect to temperature regulation, power supply, and data transmission. These technical shortcomings lead to higher weight and greater development costs.

Table II. Weight Balance for a Solar Probe with 22.5 kg of Scientific Instruments

		Weight (kg)	Capacity (watts)
1.	Measuring Instruments		
1.1	Plasma mass spectrometer	10.0	5.0
1.2	Magnetometer (Förster probe)	3.5	5.0
1.3	Cosmic ray detector	4.0	2.0
1.4	Zodiacal light spectrometer	4.0	2.0
1.5	Meteoroid detector	1.0	2.0
		22.5	16.0
2.	Data Processing and Storage ($1.3 \cdot 10^6$ bits per 24 hours)		
2.1	Analog/digital transducer	0.8	0.3

		Weight (kg)	Capacity (watts)
2.2	Digital-differential analyzer	2.7	1.0
2.3	Encoder	1.0	0.5
2.4	Tape storage unit (time storage; $1.5 \cdot 10^6$ bits)	1.8	2.1
2.5	Cell storage for experiments 1 + 3 ($1.36 \cdot 10^5$ bits)	2.8	10.0
2.6	Address generator	0.5	0.4
2.7	Command decoder	1.2	0.4
2.8	Sequencer	2.5	2.0
2.9	Computer	2.0	1.5
		15.3	18.2
3.	**Data Transmission and Command Reception** (3.5 hours daily 100 bits/sec)		
3.1	Modulator	0.3	0.8
3.2	Transmitter (15 w 2295 Mhz)	0.5	0.7
3.3	Power amplifier	7.5	37.5
3.4	Synchro-generator and time-signal transmitter	0.5	0.5
3.5	Command receiver	0.8	1.0
3.6	Non-directional antenna	0.5	-
3.7	Directional antenna (15 db gain)	4.0	-
3.8	Diplexer and Coaxial circuit-breaker	1.5	0.5
3.9	Earth sensor (for antenna)	2.8	6.5
		18.4	47.5
4.	**Guidance**		
4.1	Sun sensor (coarse + fine)	0.6	1.5
4.2	Canopus sensor	2.2	2.5
4.3	Electronic guidance instruments	3.0	4.0
4.4	Guidance gas	1.0	-
4.5	Gas tank	4.0	=
4.6	Pressure and temperature signal transmitter	0.2	-
4.7	Valves, pressure reducer, filters	1.9	-
4.8	Gas nozzles (12)	0.9	-
4.9	Tubes and hoses	0.4	-
		14.2	8.0

		Weight (kg)	Capacity (watts)
5.	Power Supply and On-Board Electronic Equipment		
5.1	Solar cell surface	9.3	-
5.2	Propulsion mechanism	6.0	-
5.3	Capacity regulater	1.0	2.0
5.4	Voltage transformer	2.5	10.0
5.5	Buffer and auxiliary battery	1.5	-
5.6	Voltage transformer 25w/500v	2.5	2.5
5.7	Measurement transmitter	4.5	1.0
		27.3	15.5
6.	Structure		
6.1	Plugs and Cables	7.0	
6.2	Base plate	7.7	
6.3	Cylinder	4.6	
6.4	Cone	7.0	
6.5	Sail (solar cell surface) and reinforcements	8.5	
6.6	Heat shield	3.0	
		37.8	
TOTALS including 10% safety margin but without redundancy		149.0 kg	115.7 watts

A weight balance-sheet is presented in Table II, but it was not possible to take reduncancy into account. This last has to do with the reliability of components, the useful life attained, and the probability of successful accomplishment of the mission (which is to be estimated at at least 80%).

The weight of the solar probe will be somewhat higher than the totals shown for these reasons.

Table III. The Five Proposed Experiments for the Solar Probe
(DKfW Probe Committee "Solar Probe")

	Subject	Measuring Instrument	Weight (kg)	Capacity (watts)	Minimal Flow of Information (bits/sec)
1	PLASMA (Dr. Pinkau, MPI [Max Planck Institut], Garching)	Mass Spectrometer	10	5	10
2	MAGNETIC FIELD (Neubauer/Dr. Siemann, Institut für Geophysik, Brunswick)	Förster Probe	3.5	5	1.7
3	COSMIC RADIATION (Dr. Wibberenz, Inst. für Kernphysik, Kiel)	Semiconductors, Cherenkov Telescope	4.0	2	1
4	ZODIACAL LIGHT (Prof. Elsässer, Landessternwarte, Heidelberg	Two-Color Spectrometer	4	2	0.1
5	MICROMETEOROIDS (Prof.Dr. Sitte, MPI, Heidelberg)	Meteoroid Counter	1	2	0.4
			22.5 kg	16 watts	13.2 bits/s

4. Broadened Mission Profiles

4.1 Venus Swing-By

In view of the fact that an approach to the sun within 0.3 A.U. can hardly be achieved with the solid-fuel modulus BURNER II, the possibility of the Venus swing-by should be re-examined. In that case perihelion distances of 0.25 A.U. and less can be achieved, and a possible launching time would be 10 June 1972.

4.2 Secondary Mission Mercury Approach

If we are willing to dispense with a Venus swing-by, there is another possibility of heightening the scientific value of the mission and so raising the efficiency of the investment: a distant flight past Mercury after satisfying the principal tasks of the probe. The disturbance of the orbit by Mercury to be observed would permit an improvement on the present value for the mass of Mercury without this mission profile's requiring great additional expenditure.

4.3 Long-Term Program

It would be desirable not to consider only a single solar-probe mission, but to provide from the beginning a program of at least two probes which would be launched at an interval of some years. In that case we could content ourselves at first with a smaller probe, which is designed for only a perihelion distance of 0.3 A.U. (put into orbit with ATLAS-CENTAUR-BURNER II). A second mission could then follow later, in which with fuller instrumentation and a Venus swing-by an approach to within about 0.22 A.U. of the sun would be achieved (put into orbit with ATLAS-CENTAUR + high-power propulsion modulus HetAM). (hochenergetisches Antriebsmodul).

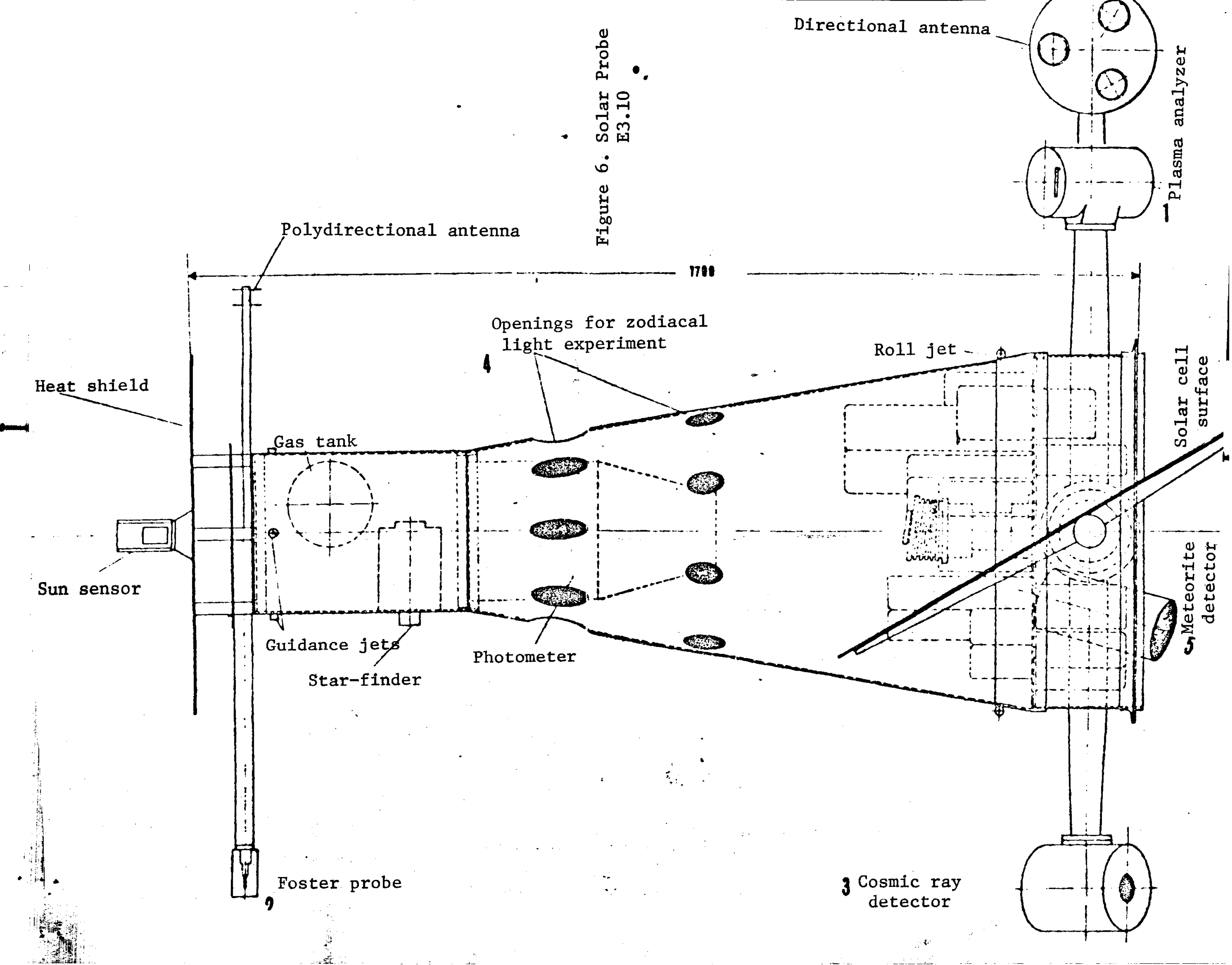
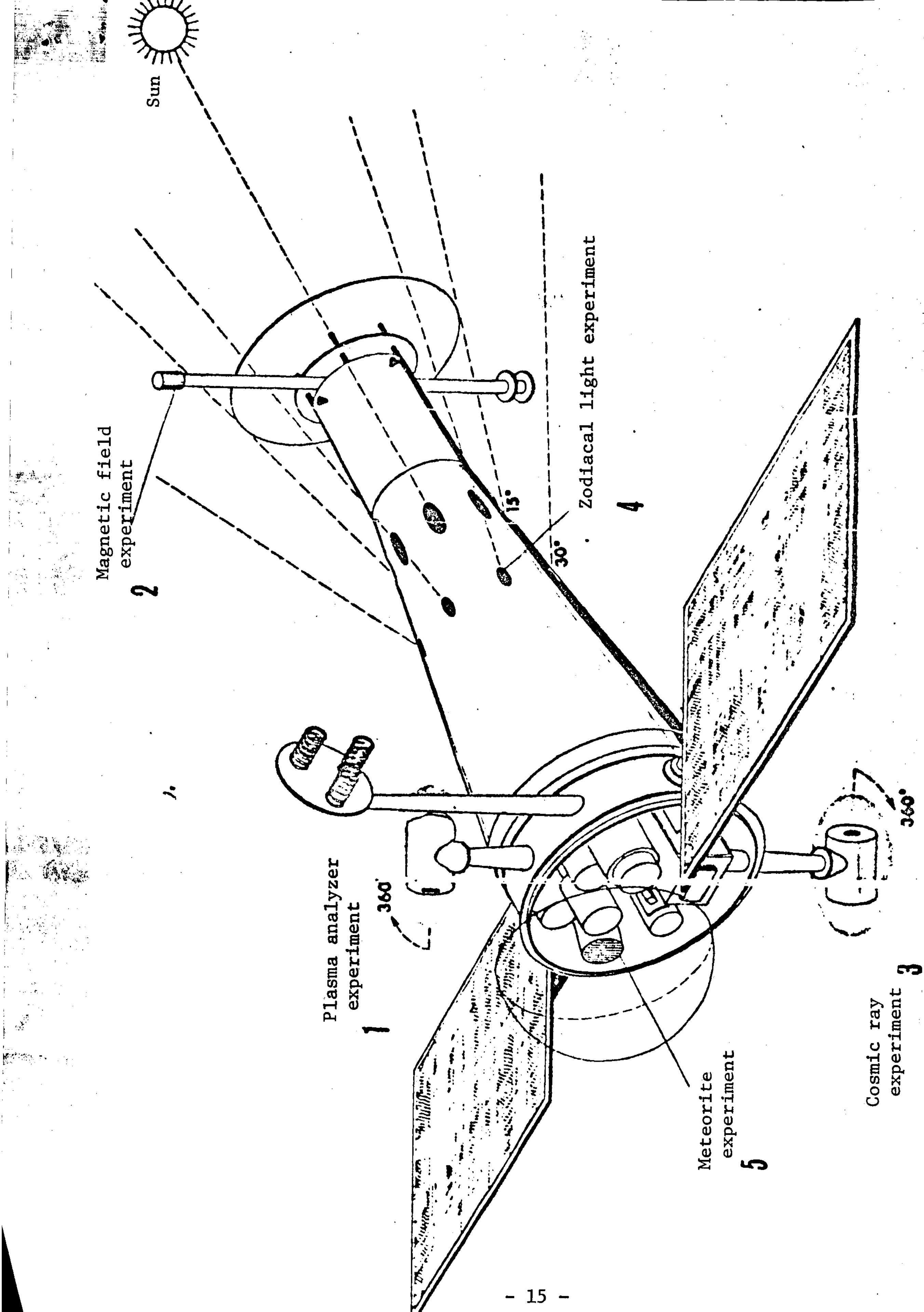


Figure 6. Solar Probe E3.10


Sun
Magnetic field experiment
2
Zodiacal light experiment
4
15°
30°
Plasma analyzer experiment
1
360
360°
Meteorite experiment
5
Cosmic ray experiment
3